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Revising the WAsP-Park's model wake decay coefficient for different atmospheric stabilities

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Introduction

Prediction of wind farm power outputs is difficult, particularly for large-size farms and when the variation in stability conditions is strong. CFD methods are applied for multiple turbines using LES and on larger wind farms using RANS turbulence models. LESs remain too expensive and still have problems to preserve turbulence over large distances. RANS methods have numerical and physical limitations and approach the multi-scale physics of turbine wake using a simplistic single scale model [6]. The majority of the CFD methods assume neutral atmospheric conditions. Although engineering wake models are based in many assumptions and limited to medium-size wind farms, they are million times faster than RANS/LES and can be used for short-term farm power predictions under a wide range of scenarios. The Park model [3] used in WAsP [4] makes use of the wake decay coefficient k_w to estimate the speed deficit downstream of a(a cluster of) wind turbine(s). [5] found that in order to match the speed deficits estimated by the infinite wind farm boundary layer (IWFBL) model of Frandsen [2] to those of the Park model, the wake decay had to be modified depending on stability, roughness and turbine-turbine distance. Here we present part of the findings from [5] and discuss their main implications

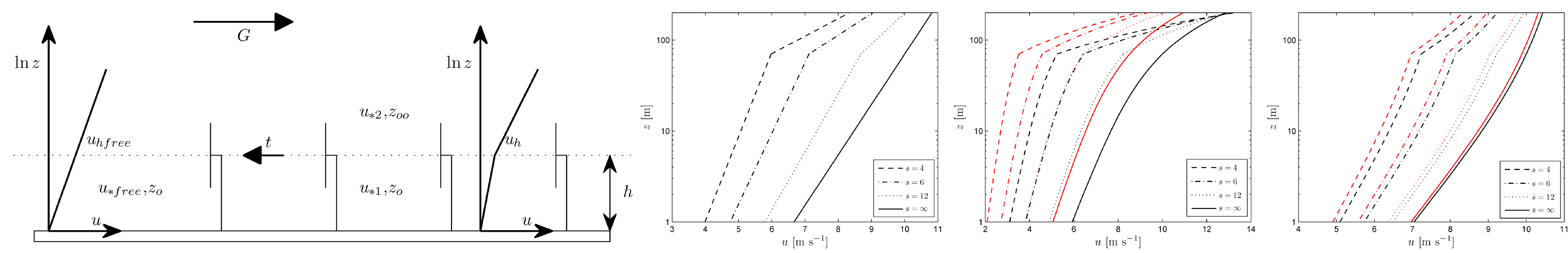

Figure 1: (left) The infinite wind farm boundary layer model of Frandsen. Offshore wind profiles for different stabilities: neutral-$L = \infty$ m (middle), stable-$L = 200$ m (right), unstable-$L = -200$ m (right most). Versions 1 (black) and 2 (red) with $C_t = 0.88$, $h = 70$ m and $u_{hfree} = 10$ m s^{-1}

Background

The IWFBL model of Frandsen assumes a two-layer atmosphere within an infinite wind farm (above and below hub height h–Fig. 1). By linking the shear of both layers at h, he found the wind speed reduction R_u, i.e. the ratio of the wind speed within the farm u_h to the free wind speed,

$$R_u = \frac{1+K_2\sqrt{K_1^{-2}}}{1+K_2\sqrt{K_1^{-2}+c_t}}, \qquad (1)$$

where $K_2 = (1/\kappa)\ln[G/(h f_p)]$, $K_1 = (1/\kappa)\ln(h/z_o)$, $f_p = f_c \exp(A_*)$, $c_t = (\pi/8)[C_t/(s_r s_f)]$, κ being the von Kármán constant, G the geostrophic wind speed, z_o the roughness length, f_c the Coriolis parameter, A_* a modified A-parameter from the resistant law constants, C_t the thrust coefficient, and s_r and s_f the along and cross dimensionless turbine-turbine distances, respectively.

Following the approach by Emeis [1] one can extend Eq. 1 by multiplying the dimensionless wind shear ϕ_m from MOST to K_2 and subtracting the stability correction ψ_m to the log term in K_1. Both ϕ_m and ψ_m are functions of height and of the Obukhov length L. We called this version 1.

Another approach (hereafter version 2) is to extend the shear stresses u_{*1} and u_{*2} using the ψ_m functions and the diabatic wind profile. Following the derivation of Eq. (1), K_1 has to be corrected as in version 1 and K_2 becomes u_* dependent, since A_* is u_* dependent through μ_o ($\mu_o = \kappa\ u_*/(f_c\ L)$). Therefore, K_2 is different for the undisturbed atmosphere (in the numerator in Eq. 1 we use $K_2(u_{*free})$) than for the atmosphere within the farm (in the denominator in Eq. 1 we use $K_2(u_{*2})$. u_{*2} is found iteratively using the expression for the effective roughness z_{oo},

$$z_{oo} = h\ \exp\left[-\kappa/\sqrt{c_t + K_1^{-2}} - \psi_m(h/L)\right]. \qquad (2)$$

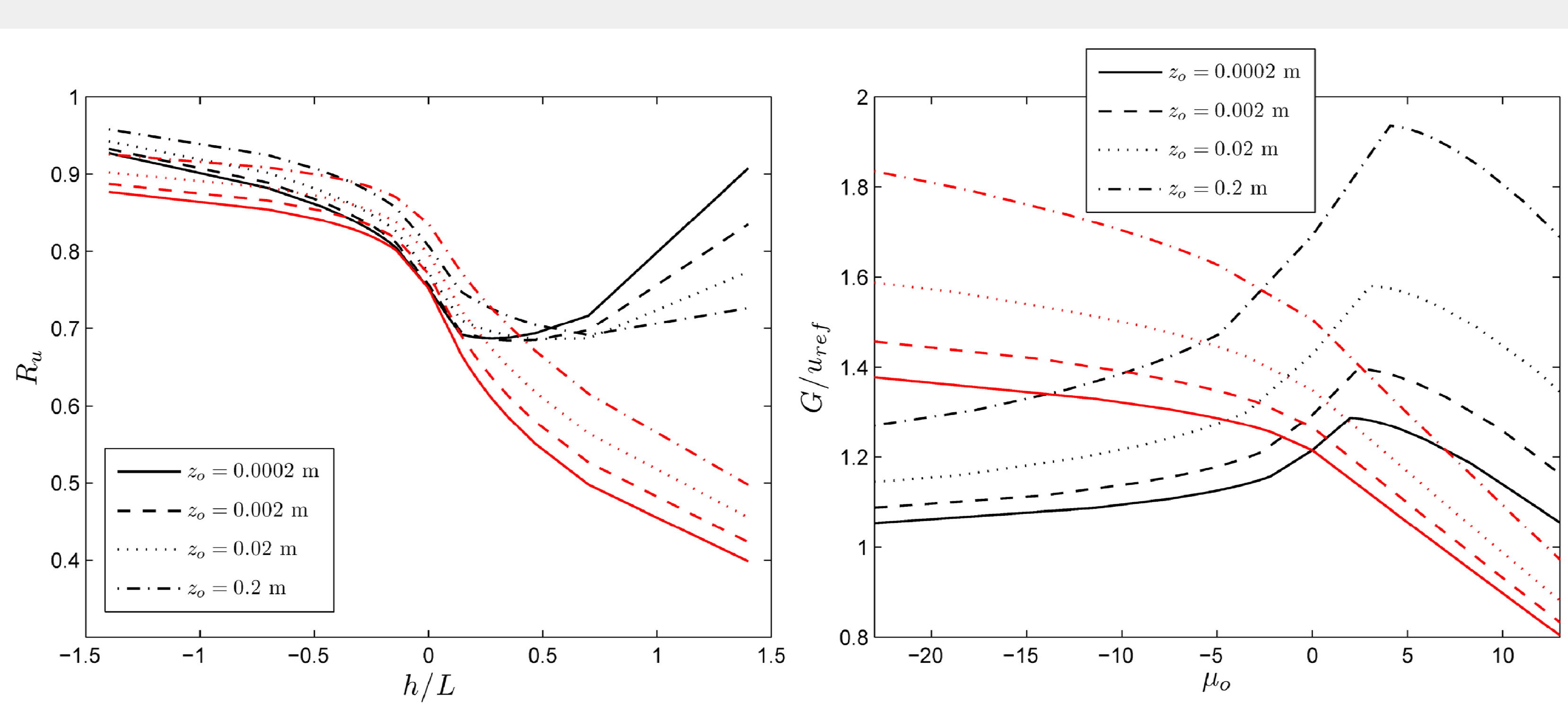

Figure 2: Wind speed reduction (left) and normalized geostrophic wind speed (right) for versions 1 (red) and 2 (black) with $s = 7$, $C_t = 0.88$, $h = 70$ m and $u_{hfree} = 10$ m s^{-1}

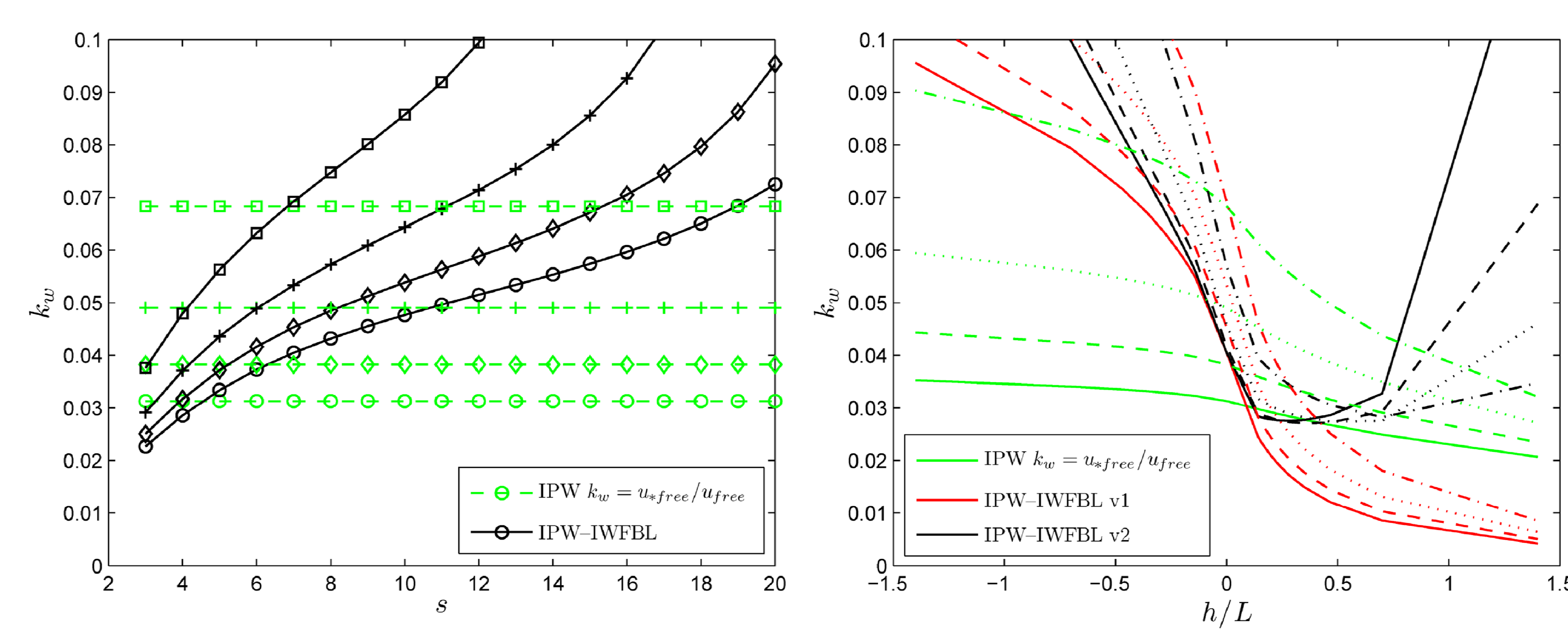

Figure 3: Wake decay coefficient for neutral (left) and diabatic conditions (right) with $s = 7$, $C_t = 0.88$, $h = 70$ m and $u_{hfree} = 10$ m s^{-1}

Results & Discussion

Fig. 1 shows wind profiles within an offshore farm for different turbine distances and stabilities, where the kink in the profile appears at h. Both versions show the same wind profiles under neutral conditions and for the unstable and stable cases, version 1' wind speeds are lower than those of version 2.

Fig. 2-left shows R_u for a range of stabilities and roughnesses. For version 1, R_u always increases with z_o with a higher stability variation. Version 2 follows the behavior of 1 with a peak at a positive h/L. This is because u_{hfree} is used as the input parameter and for $h = 70$ m and stable conditions, the stability corrections from MOST to the wind speed are too high. The peak is also observed in the normalized geostrophic wind speed graph in Fig. 2-right.

The wake decay coefficent has been estimated for the infinite Park model so that it matches R_u of the two versions of the extended IWFBL model. In Fig. 3 this adjusted k_w is compared to the expression $k_w = u_{*free}/u_{hfree}$ for neutral (left frame) and diabatic conditions (right frame). For a wide number of turbine distances, roughnesses and stabilities, the adjusted k_w is much lower than the recommended WAsP value (0.050 and 0.075 for offshore and onshore sites, respectively). The value of the adjusted k_w increases with increasing roughness, turbine separation and instability.

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